

New Record of Seven Soil Ciliates (Ciliophora: Stichotrichia) from Korea

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ABSTRACT

The seven unrecorded ciliates were collected from soil samples in Korea. The morphological study of these ciliates was performed based on observation of both living and stained cells: *Rigidocortex quadrinucleatus* Bharti, Kumar and La Terza, 2017, *Rigidohymena tetracirrata* (Gellért, 1942) Berger, 2011, *Urosoma salmastra* (Dragesco and Dragesco-Kernéis, 1986) Berger, 1999, *Urosomoida agilis* (Engelmann, 1862) Foissner, 1982, *Rigidosticha italiensis* Bharti, Kumar and La Terza, 2016, *Eschaneustyla terricola* Foissner, 1982 and *Pseudokeronopsis similis* (Stokes, 1886) Borror and Wicklow, 1983. Among the seven genera in this study, the genus *Rigidosticha* Bharti, Kumar and La Terza, 2016 is firstly reported in Korea. In this study, we provide brief descriptions and remarks for the ciliates with photographs.

Keywords: Korea, protargol staining, soil, stichotrich, terrestrial habitat

INTRODUCTION

Ciliates in Korea were firstly reported by Huruyama (1931), and more than 450 species have been recorded to date. Of these, more than 100 species were known as soil ciliates (Jung et al., 2017; Kwon et al., 2019). Soil ciliates are known to play important ecological roles by feeding on fungi, other protists and bacteria in the soil microbial food web, and contributing nutrient cycling by absorbing nutrients from the bacterial biomass and transferring the nutrients to the macrofauna (Lynn, 2008; Oshima et al., 2020). In addition, soil ciliates have been suggested as major biomarkers of soil environment because of their specific vertical distribution and their excellent results of community structure changes according to soil contaminants (Foissner, 1999; Lara and Acosta-Mercado, 2012).

In this study, seven soil ciliates assigned in the seven stichotrichian genera were identified, and all are new to Korea. Among the seven genera, the genus *Rigidosticha* Bharti, Kumar and La Terza, 2016 is firstly reported in Korea. We provide brief descriptions and remarks for the ciliates with photographs.

MATERIALS AND METHODS

Ciliates were collected from terrestrial habitats. Seven ciliates were isolated from six soil samples. The information about collected time and the locality is described in the 'Material examined' section for each species. The soil samples were dried for two weeks, transferred to Petri dishes, mixed with mineral water, and incubated at room temperature (20°C) (Foissner et al., 2002).

The morphology was observed using a stereo microscope (SZH10; Olympus, Tokyo, Japan) and an optical microscope (Leica DM2500; Wetzlar, Germany) at $\times 50$ to $\times 1,000$ magnification. Protargol staining was performed as described by Foissner (2014) (Procedure A). Terminology and classification were performed according to Berger (1999), Foissner (2016) and Lynn (2008).

RESULTS AND DISCUSSION

Phylum Ciliophora Doflein, 1901
Class Spirotrichea Bütschli, 1889
Subclass Stichotrichia Small and Lynn, 1985

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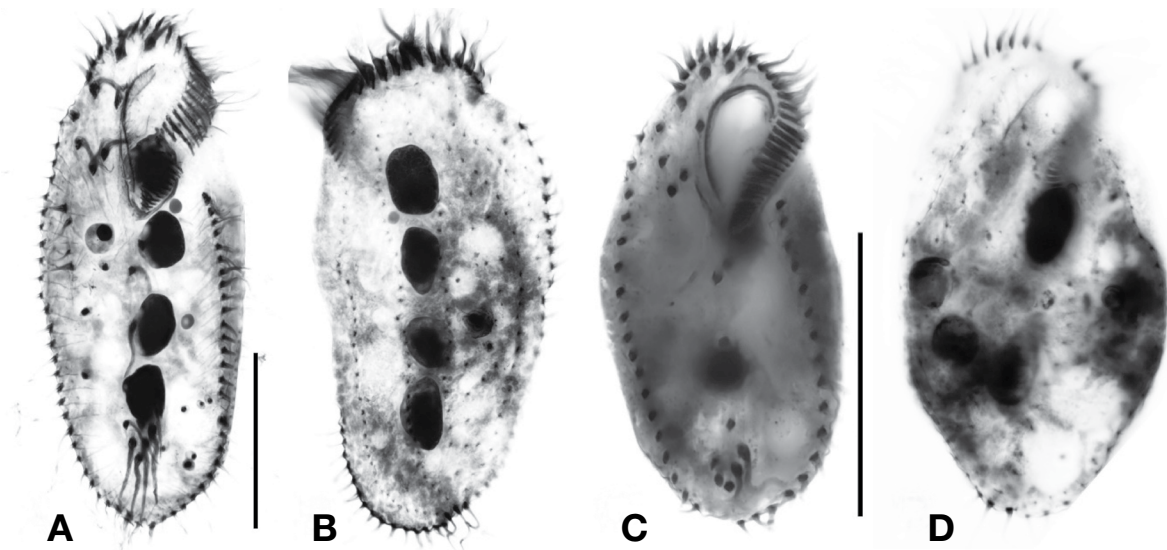


Fig. 1. *Rigidocortex quadrinucleatus* (A, B) and *Rigidohymena tetracirrata* (C, D) after protargol impregnation. A, C, Somatic and oral ciliature on ventral sides; B, D, Dorsal view showing kineties. Scale bars: A, C=50 μ m.

Order Sporadotrichida Fauré-Fremiet, 1961

Family Oxytrichidae Ehrenberg, 1830

Genus *Rigidocortex* Berger, 1999

¹**Rigidocortex quadrinucleatus* Bharti, Kumar and La Terza, 2017 (Fig. 1A, B)

Rigidocortex quadrinucleatus Bharti, Kumar and La Terza, 2017: 678, figs. 1–3, table 1.

Material examined. Soil sample from Nonhyeon-dong, Incheon, Korea (37°24'47.4"N, 126°44'45.0"E) on Jun 2019.

Diagnosis. Size about 132–173 \times 60–92 μ m in protargol preparation; rigid body elliptical shape; contractile vacuole positioned at left side of the center of the body; 37–49 adoral membranelles; 4 macronuclear nodules with 2 or 3 micronuclei; 3 frontal cirri; 4 frontoventral cirri; 1 buccal cirrus; 3 postoral cirri; 1 left (21–31 cirri) and 1 right (19–29 cirri) marginal row; 2 pretransverse cirri; 5 transverse cirri; 5 dorsal kineties and 2 dorsomarginal kineties; 3 caudal cirri.

Distribution. Italy and Korea.

Remarks. The Korean population of *Rigidocortex quadrinucleatus* is consistent with the type population (Italian population) described by Bharti et al. (2017). However, the Korean population differs from the Italian population in terms of the number of postoral cirri (invariably 3 vs. 3–5) and number of transverse cirri (invariably 5 vs. 5 or 6) (Bharti et al., 2017). The genus *Rigidocortex* consists of two species, *R. quadrinucleatus* and *R. octonucleatus* (Foissner, 1988) Berger, 1999

(Berger, 1999). *Rigidocortex quadrinucleatus* mainly differs from *R. octonucleatus* in the number of macronuclear nodules (4 vs. 8).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the Nakdonggang National Institute of Biological Resources (NNIBRIV50290).

Genus *Rigidohymena* Berger, 2011

²**Rigidohymena tetracirrata* (Gellért, 1942) Berger, 2011 (Fig. 1C, D)

Cyrtohymena tetracirrata Foissner, 1989: 196; Berger, 1999: 317, fig. 102a–k, table 20.

Rigidohymena tetracirrata Berger, 2011: 548.

Material examined. Soil sample from Eurwnag-dong, Incheon, Korea (37°26'47"N, 126°23'40"E) on Feb 2018.

Diagnosis. Cell size about 62–108 \times 38–45 μ m in protargol preparations; rigid body; 33–38 adoral membranelles; 2 macronuclear nodules with about 2 micronuclei; 3 frontal cirri; 1 buccal cirrus; 4 cirri in frontoventral cirri; 3 postoral ventral cirri; 2 pretransverse and 4 transverse cirri; 1 left (16–17 cirri) and 1 right (14–17 cirri) marginal cirral row; 4 dorsal kineties and 2 dorsomarginal kineties; 3 caudal cirri.

Distribution. Austria, Greece, Hungary, South Africa and Korea.

Remarks. The Korean population of *R. tetracirrata* morphologically corresponds with the Hungarian, Greek and South

Korean name: ¹*사핵경피하모충 (신칭), ²*사횡극모관막하모충 (신칭)

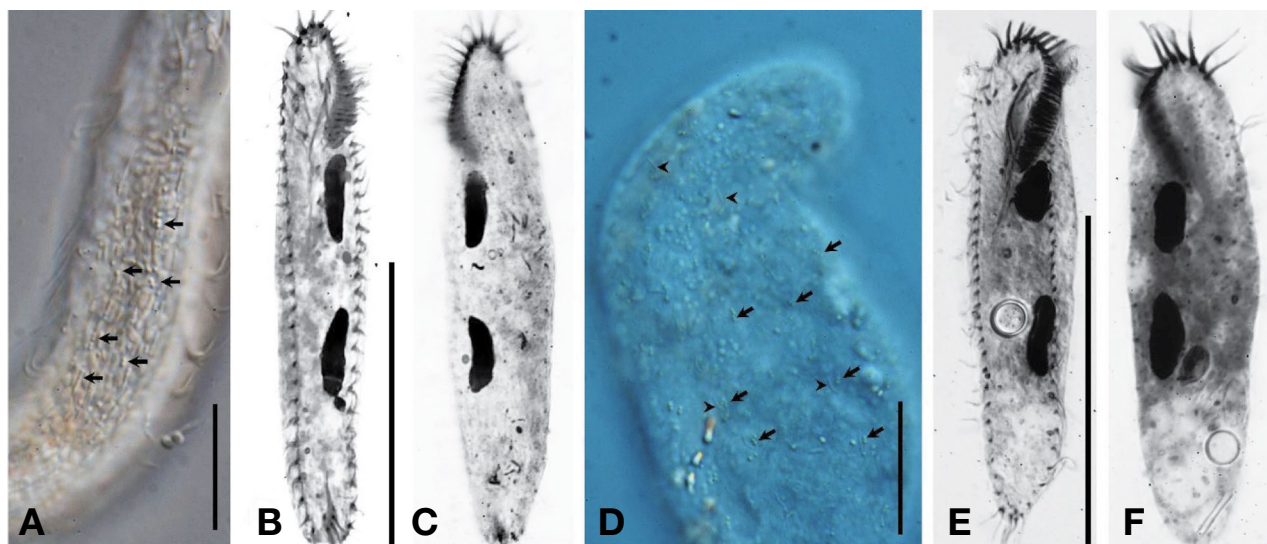


Fig. 2. *Urosoma salmastra* from life (A) and after protargol impregnation (B, C), and *Urosomoida agilis* from life (D) and after protargol impregnation (E, F). A, Cortical granules on dorsal side (arrows); B, E, Somatic and oral ciliature on ventral sides; C, F, Dorsal kineties on dorsal side; D, Dorsal bristles (arrowheads) and cortical granules (arrows). Scale bars: A, D=10 μ m, B, E=50 μ m.

African populations in terms of body size, and the ventral and dorsal ciliature (Gellért, 1942; Berger and Foissner, 1987; Song, 2004). *Rigidohymena tetracirrata* is distinguished from *R. candens* (Kahl, 1932) Berger, 2011 in the number of transverse cirri (4 vs. 5) (Berger, 2011; Chen et al., 2013).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the Nakdonggang National Institute of Biological Resources (NNIBR2019525PR2).

Genus *Urosoma* Kowalewski, 1882

¹**Urosoma salmastra* (Dragesco and Dragesco-Kernéis, 1986) Berger, 1999 (Fig. 2A–C)

Urosoma salmastra Berger, 1999: 424, fig. 133a–c, table 24.

Material examined. Soil sample from Songdo-dong, Incheon, Korea (37°23'27.4"N, 126°40'00.3"E) on Jan 2019.

Diagnosis. Size about 71–105 × 12–22 μ m in protargol preparation; body flexible with slender to elliptical shape; contractile vacuole positioned at left side of the center of the body; cortical granules present; 2 macronuclear nodules with 1–3 micronuclei; 18–25 adoral membranelles; 3 frontal cirri; 4 frontoventral cirri; 1 buccal cirrus; 3 postoral ventral cirri; 1 pretransverse ventral cirri; 3 or 4 transverse cirri; 1 left (19–25 cirri) and 1 right (21–29 cirri) marginal row; 3 dorsal kineties and 1 dorsomarginal kinety; 3 or 4 caudal cirri.

Distribution. Benin, China, France and Korea.

Remarks. The Korean population of *U. salmastra* corresponds to type population (Benin population) and Chinese populations in terms of the elliptical body shape, two macronuclear nodules and cortical granules (Dragesco and Dragesco-Kernéis, 1986; Wang et al., 2017). However, the Korean population differs from the Chinese population in terms of the number of pretransverse ventral cirri (invariably 1 vs. 1 or 2) (Wang et al., 2017). *Urosoma salmastra* can be separated from *U. emarginata* (Stokes, 1885) Berger, 1999 in the number of adoral membranelles (18–25 vs. 26–34), number of pretransverse ventral cirri (1 vs. 2), number of transverse cirri (3 or 4 vs. 4 or 5) and right posterior end (rounded vs. emarginated) (Foissner, 1983; Berger, 1999).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the National Institute of Biological Resources (NIBRPR0000110232).

Genus *Urosomoida* Foissner, 1982

²**Urosomoida agilis* (Engelmann, 1862) Foissner, 1982 (Fig. 2D–F)

Urosomoida agilis Foissner, 1982: 115, fig. 34a–e, table 27; Berger, 1999: 347, fig. 110a–q, tables 3, 4, 22.

Material examined. Soil sample from Joojin-ri, Pyeongchang-gun, Gangwon-do, Korea (37°23'54.1"N, 128°25'25.1"E) on Oct 2018.

Diagnosis. Size about 69–102 × 18–30 μ m in protargol prepa-

Korean name: ¹*짧은내구막공지하모충 (신칭), ²*말단횡극모하모충 (신칭)

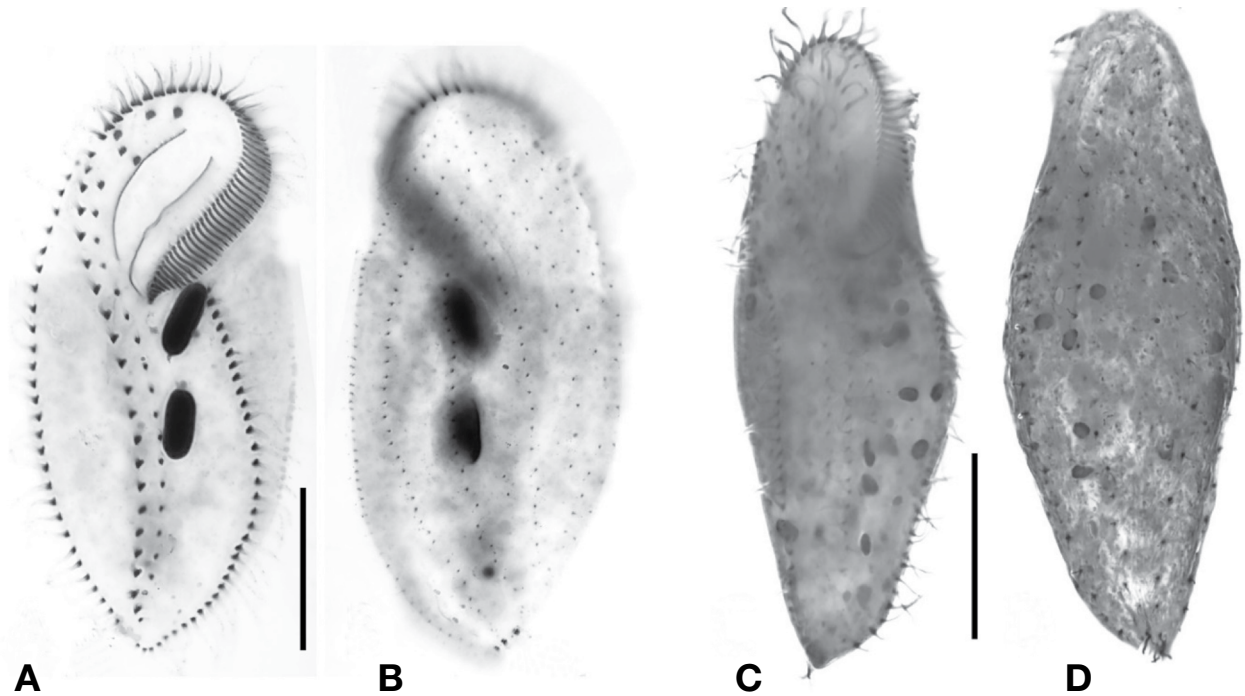


Fig. 3. *Rigidosticha italiensis* (A, B), *Eschaneustyla terricola* (C, D) after protargol impregnation. A, C, Somatic and oral ciliature on ventral side; B, D, Dorsal kineties on dorsal side. Scale bars: A, C=50 μ m.

ration; body slender to elliptical shape; Contractile vacuole at left midbody; cortical granules present; 2 macronuclear nodules with 1–4 micronuclei; 23–30 adoral membranelles; 3 frontal cirri; 4 frontoventral cirri; 1 buccal cirrus; 3 postoral ventral cirri; 1 pretransverse ventral cirri; 2 transverse cirri; 1 left (21–30 cirri) and 1 right (22–30 cirri) marginal cirral row; 4 dorsal kineties; 3 caudal cirri.

Distribution. Austria, Belgium, Czech, Germany, Italy, USA and Korea.

Remarks. The Korean population of *U. agilis* is very similar to type population (German population) and the Austrian population morphologically (Foissner, 1982). However, the former mainly differs from the latter by the number of postoral ventral cirri (3 vs. 1–3) (Foissner, 1982). *Urosomoida agilis* differs from *U. granulifera* Foissner, 1996 in terms of the number of transverse cirri (2 vs. 3 or 4) and the number of caudal cirri (3 vs. 2) (Foissner, 1996).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the National Institute of Biological Resources (NIBRPR0000110233).

Family Rigidotrichidae Foissner and Stoeck, 2006
Genus *Rigidosticha* Bharti, Kumar and La Terza, 2016

¹**Rigidosticha italiensis* Bharti, Kumar and La Terza, 2016 (Fig. 3A, B)

Rigidosticha italiensis Bharti, Kumar and La Terza, 2016: 112, figs. 1–5; table 1; Bharti and Kumar, 2019: 112, fig. 1B.

Material examined. Soil sample from Seokhwa-ri, Cheongju-si, Chungcheongbuk-do, Korea (36°38'3.54"N, 127°21'18.44"E) on Jun 2019.

Diagnosis. Cell size about 177 \times 82 μ m in protargol preparation; rigid body elliptical shape; 52 adoral membranelles; 2 macronuclear nodules; 3 micronuclei; 3 frontal cirri; 2 frontoterminal cirri; 1 buccal cirrus; 1 parabuccal cirrus; 18 cirri in midventral pairs; pretransverse cirri absent; 2 transverse cirri; 1 left (35 cirri) and 1 right (29 cirri) marginal cirral row; 3 bipolar dorsal kineties and 6 dorsomarginal kineties; 3 caudal cirri.

Distribution. India, Italy and Korea.

Remarks. The Korean population of *R. italiensis* corresponds to type population (Italian population) and the Indian population in two macronuclear nodules and the ventral and dorsal ciliature (Bharti et al., 2016; Bharti and Kumar, 2019). However, the Korean population only differs from the Italian population in terms of cell size (177 \times 82 μ m vs.

Korean name: ¹*강직하모충 (신칭)

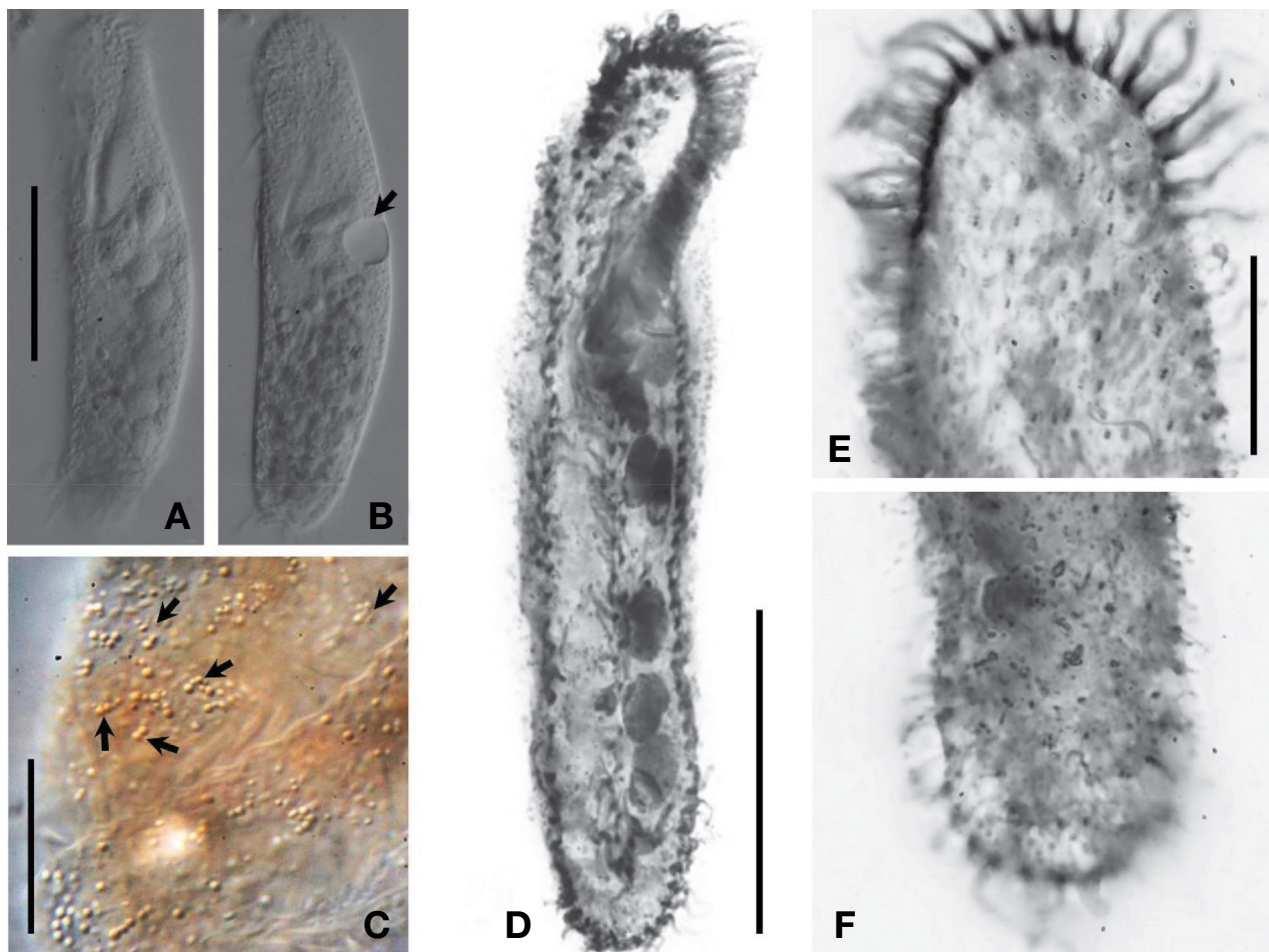


Fig. 4. *Pseudokeronopsis similis* from life (A–C) and after protargol impregnation (D–F). A, Typical body shape in vivo; B, Contractile vacuole (arrow); C, Cortical granules on ventral side (arrows); D, Somatic and oral ciliature on ventral side; E, F, Anterior and posterior dorsal kineties on dorsal side. Scale bars: A, D=50 µm, C, E=10 µm.

200–284 × 84–147 µm) (Bharti et al., 2016).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the National Institute of Biological Resources (NIBRPR0000110236).

Order Urostylida Jankowski, 1979

Family Epiclintidae Wicklow and Borror, 1990

Genus *Eschaneustyla* Stokes, 1886

¹**Eschaneustyla terricola* Foissner, 1982 (Fig. 3C, D)

Eschaneustyla terricola Foissner, 1982: 37, fig. 3a–e, table 6; Berger, 2006: 1150, figs. 233a–e, 234a–o, 235a, b, table 44.

Material examined. Soil sample from Eum-ri, Jeju-si, Je-

ju-do, Korea (33°24′15.2″N 126°20′59.6″E) on Oct 2018.

Diagnosis. Cell size 129–175 × 36–65 µm in protargol impregnation; body flexible with slender to elliptical shape; 39–41 adoral membranelles; cortical granules present; 37–58 macronuclear nodules with 1–4 micronuclei; frontal cirri rows arranged in frontal field; 9–31 frontoterminal cirri; midventral complex composed of 2 or 3 midventral cirral rows; 1 left (39–52 cirri) and 1 right (34–49 cirri) marginal row; transverse cirri lacking; 4 dorsal kineties; 4–7 caudal cirri.

Distribution. Austria, Costa Rica and Korea.

Remarks. The Korean population of *E. terricola* is consistent with type population (Austrian population) in the number of adoral zone of membranelles, the number of macronuclear nodules, number of marginal cirri and dorsal

kinetics, but the former only differs from the latter in the number of most left frontal cirri (3 vs. 1) (Foissner, 1982). *Eschaneustyla terricola* differs from the most similar species *E. lugeri* Foissner, Agatha and Berger, 2002 by number of adoral zone of membranelles (39–41 vs. 48–64), number of buccal cirri (2 vs. 3–5) and number of caudal cirri (4–7 vs. 8–11) (Foissner et al., 2002).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the National Institute of Biological Resources (NIBRPR0000110229).

Family Pseudokeronopsidae Borror and Wicklow, 1983
Genus *Pseudokeronopsis* Borror and Wicklow, 1983

^{1*}*Pseudokeronopsis similis* (Stokes, 1886) Borror and Wicklow, 1983 (Fig. 4A–F)

Pseudokeronopsis similis Borror and Wicklow, 1983: 110, fig. 23; Shi et al., 2007: 41, fig. 1, table 1.

Material examined. Soil sample from Eum-ri, Jeju-si, Jeju-do, Korea (33°24'15.2"N, 126°20'59.6"E) on Oct 2018.

Diagnosis. Size about 130–170 × 40–60 µm in vivo; body slender to elliptical shape; contractile vacuole positioned at left side of the center of the body; cortical granules present; 31–47 adoral membranelles; 7–16 macronuclear nodules with 2–6 micronuclei; frontal cirri formed bicorona; 2 frontoterminal cirri; 1 buccal cirrus; midventral complex composed of midventral pairs only; 1 left (32–54 cirri) and 1 right (32–42 cirri) marginal cirral row; 5–9 transverse cirri; 5–6 dorsal kinetics; dorsal bristles 2 µm long.

Distribution. Austria, Azerbaijan, China, Germany, Hungary, Poland, Slovakia, USA and Korea.

Remarks. The Korean population of *P. similis* can be distinguished from the type population (American population) by the transverse cirri (5–9 vs. 12–14) (Stokes, 1886). It is also very similar to the Chinese population in Guangdong but differs mainly in the number of adoral zone of membranelles (31–47 vs. 48–58) (Liu and Jin, 2000; Shi et al., 2007). However, other Chinese population in Mohe differs from the Korean population in terms of body size (220–350 × 70–90 µm vs. 130–170 × 40–60 µm), the number of adoral zone of membranelles (61–88 vs. 31–47) and number of left and right marginal row cirri (51–77 and 50–75 vs. 32–54 and 32–42) (Shi et al., 2007). Thus, the morphological features of the Korean population were similar to those of the Guangdong population. *Pseudokeronopsis similis* should be compared with other congeners, such as *P. elongata* (Wang and Nie, 1935) Shi et al., 2007. *Pseudokeronopsis similis* differs from *P. elongata* in terms of the number of macronuclear nodules (7–

16 vs. 4) (Wang and Nie, 1935).

Voucher slide. One slide with protargol-impregnated specimens was deposited at the National Institute of Biological Resources (NIBRPR0000110231).

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CONFLICTS OF INTEREST

Gi-Sik Min, a contributing editor of the Animal Systematics, Evolution and Diversity, was not involved in the editorial evaluation or decision to publish this article. All remaining authors have declared no conflicts of interest.

ACKNOWLEDGMENTS

This study was supported by grants from the National Institute of Biological Resources (NIBR201902204, NIBR 201928201) and the Nakdonggang National Institute of Biological Resources (NNIBR201901203) funded by the Ministry of Environment (MOE) of the Republic of Korea.

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Korean name: ^{1*}토양위각모충 (신칭)

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Received July 8, 2021
Revised July 13, 2021
Accepted July 16, 2021